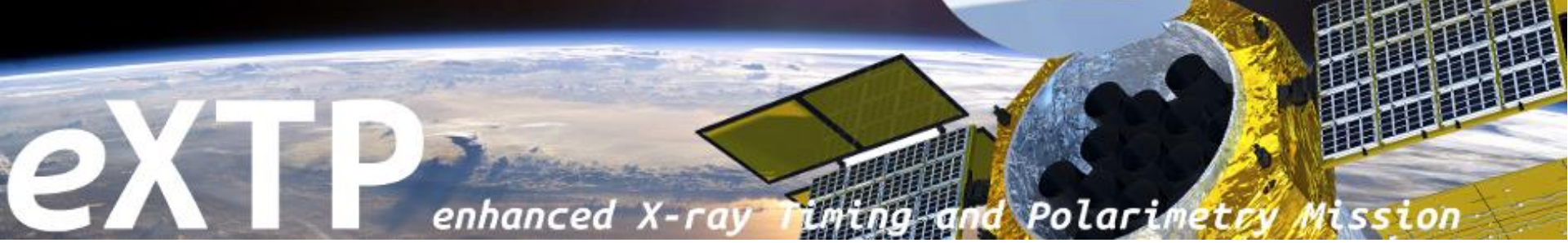


Enhanced X-ray Timing & Polarimetry (eXTP) Observatory Mission

Shuang-Nan Zhang（张双南）

Particle Astrophysics Division (PAD)

Institute of High Energy Physics (IHEP)

Chinese Academy of Sciences (CAS)

on behalf of the eXTP international consortium

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

The eXTP international consortium （science & payload developments）

- **PI: Shuang-Nan Zhang, IHEP CAS**
- **Main member institutions from China：**
  - **清華大學、哈爾濱工業大學、同濟大學、北方夜視集團、西安光機所、國家空間科學中心、國家天文臺、上海天文臺、中國科技大學、南京大學、北京大學、復旦大學、北京師範大學、廈門大學、雲南大學、廣西大學等**
- **Main member institutions from Europe：**
  - **Italy: IAPS/INAF, Univ. of Ferrara, INAF-OA Rome, Univ. of Padova, INAF-IASF Milano etc.**
  - **Germany：MPE、Univ. of Tuebingen etc.**
  - **Spain：IEEC-CSIC**
  - **Switzerland: University of Geneva etc.**
  - **Denmark：Tech. Univ. of Denmark etc.**
  - **Czech republic, Poland**
  - **Netherlands：Univ. of Amsterdam, Leiden Observatory, SRON etc**
  - **UK: MSSL/UCL, Leicester Univ. etc**
- **Other potential partners: USA, Japan, India, Russia, Taiwan, HK, … …**

（Note：red: with hardware contribution，blue: science only）

eXTP – the successor of Insight-HXMT

- Scientific objectives (core science):
  - Test General Relativity in strong-field regime
  - Determination of the equation of state (EOS) of matter at supra-nuclear densities
  - Measurement of QED effects in the presence of ultra-strong magnetic fields
- Instrument requirement: high throughput, time resolved spectroscopy and simultaneous polarimetry
- Observatory sciences, multi-messenger astrophysics
  - Variety of studies complementing the core science

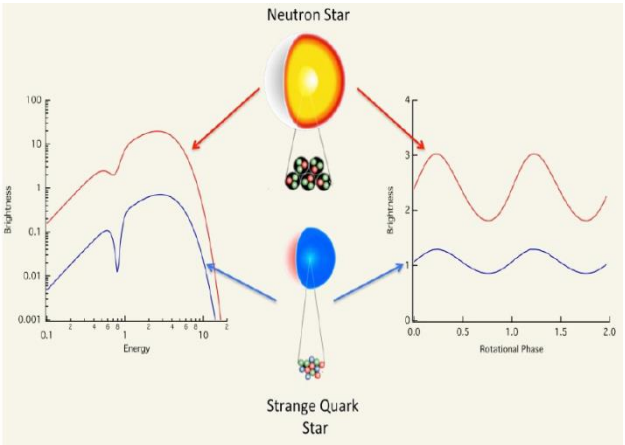
Keywords:

1 singularity (black hole)

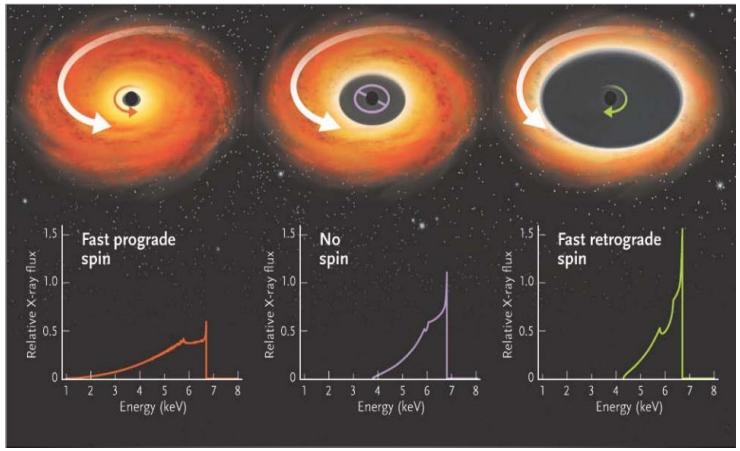
2 stars (neutron star or quark star)

3 extremes (gravity, density, magnetism)

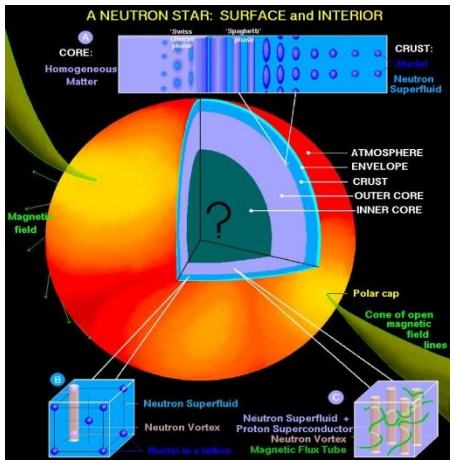
$GM/c^2r\sim1$, $10^{15}g/cm^3$, $10^{14}Gs$



Neutron star & Quark star



Extreme gravity near black hole

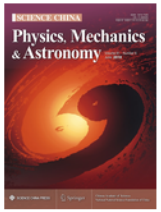


Vacuum fluctuations, Neutrons or Quarks?

White papers on eXTP (arXiv on 2018/11/29)

Five refereed papers have been accepted for publication in a special issue of SCIENCE CHINA Physics, Mechanics & Astronomy and will be available in the arXiv on 2018/11/29.

- S.-N. Zhang, A. Santangelo, M. Feroci, Y.P. Xu, et al., The enhanced X-ray Timing and Polarimetry mission - eXTP
- A. L. Watts, W.F. Yu, J. Poutanen, S. Zhang, et al., Dense matter with eXTP
- A. De Rosa, P. Uttley, L.J. Gou, Y. Liu, et al., Accretion in Strong Field Gravity with eXTP
- A. Santangelo, S. Zane, H. Feng, R.X. Xu, et al., Physics and Astrophysics of Strong Magnetic Field systems with eXTP
- J. J. M. in 't Zand, B. Enrico, J.L. Qu, X.D. Li, et al., Observatory science with eXTP



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Volume 62, Issue 2, 2019

Invited Review Astrophysics

Dense matter with eXTP Topical Collection

Anna L. Watts, Yu WenFei, Poutanen Juri, Zhang Shu, Bhattacharyya Sudip, Bogdanov Slavko, Ji Long, Patruno Alessandro, Thomas E. Riley, Bakala Pavel, Baykal Altan, Bernardini Federico, Bombaci Ignazio, Brown Edward, Cavecchi Yuri, Chakrabarty Deepto, Chenevez Jérôme, Degenaar Nathalie, Melania Del Santo, Tiziana Di Salvo, Doroshenko Victor, Falanga Maurizio, Robert D. Ferdman, Feroci Marco, Angelo F. Gambino, Ge MingYu, Svenja K. Greif, Guillot Sebastien, Gungor Can, Dieter H. Hartmann, Hebeler Kai, Heger Alexander, Homan Jeroen, Ioria Rosario, Jean in 't Zand, Kargaltsev Oleg, Kurkela Aleksi, Lai XiaoYu, Li Ang, Li XiangDong, Li ZhaoSheng, Linares Manuel, Lu FangJun, Mahmoodifar Simin, Méndez Mariano, M. Coleman Miller, Morsink Sharon, Nättilä Joonas, Possenti Andrea, Prescod-Weinstein Chanda, Qu JinLu, Riggio Alessandro, Salmi Tuomo, Sanna Andrea, Santangelo Andrea, Schatz Hendrik, Schwenk Achim, Song LiMing, Eva v Srámková, Stappers Benjamin, Stiele Holger, Strohmayer Tod, Tews Ingo, Tolos Laura, Török Gabriel, Tsang David, Urbanec Martin, Vacchi Andrea, Xu RenXin, Xu YuPeng, Zane Silvia, Zhang GuoBao, Zhang ShuangNan, Zhang WenDa, Zheng ShiJie and Zhou Xia

SCIENCE CHINA Physics, Mechanics & Astronomy 62(2), 029503 (2019)
10.1007/s11433-017-9188-4

+ Details

Invited Review

Physics and astrophysics of strong magnetic field systems with eXTP Topical Collection

Santangelo Andrea, Zane Silvia, Feng Hua, Xu RenXin, Doroshenko Victor, Bozzo Enrico, Caiazzo Ilaria, Francesco Coti Zelati, Esposito Paolo, Gonz$\acute{\rm ~a}$lez-Caniulef Denis, Heyl Jeremy, Huppenkothen Daniela, Israel Gianluca, Li ZhaoSheng, Lin Lin, Mignani Roberto, Rea Nanda, Orlandini Mauro, Taverna Roberto, Tong Hao, Turolla Roberto, Baglio Cristina, Bernardini Federico, Bucciantini Niccolo', Feroci Marco, Fürst Felix, Gögüs Ersin, Güngör Can, Ji Long, Lu FangJun, Manousakis Antonios, Mereghetti Sandro, Mikusincova Romana, Paul Biswajit, Prescod-Weinstein Chanda, Younes George, Tiengo Andrea, Xu YuPeng, Watts Anna, Zhang Shu and Zhan Shuang-Nan

SCIENCE CHINA Physics, Mechanics & Astronomy 62(2), 029505 (2019)
10.1007/s11433-018-9234-3

+ Details

Invited Review

Observatory science with eXTP Topical Collection

Jean J. M. in 't Zand, Bozzo Enrico, Qu JinLu, Li Xiang-Dong, Amati Lorenzo, Chen Yang, Donnarumma Immacolata, Doroshenko Victor, Stephen A. Drake, Hernanz Margarita, Peter A. Jenke, Thomas J. Maccarone, Mahmoodifar Simin, Domitilla de Martino, Alessandra De Rosa, Elena M. Rossi, Rowlinson Antonia, Sala Gloria, Stratta Giulia, Thomas M. Tauris, Wilms Joern, Wu XueFeng, Zhou Ping, Agudo Iván, Altamirano Diego, Atteia Jean-Luc, Nils A. Andersson, M. Cristina Baglio, David R. Ballantyne, Baykal Altan, Behar Ehud, Belloni Tomaso, Bhattacharyya Sudip, Bianchi Stefano, Bilous Anna, Blay Pere, Jo ao Braga, Brandt Søren, Edward F. Brown, Bucciantini Niccolò, Burderi Luciano, Edward M. Cackett, Campana Riccardo, Campana Sergio, Casella Piergiorgio, Cavecchi Yuri, Chambers Frank, Chen Liang, Chen Yu-Peng, Chenevez Jérôme, Chernyakova Maria, Jin ChiChuan, Ciolfi Riccardo, Costantini Elisa, Cumming Andrew, D'Aì Antonino, Dai Zi-Gao, D'Ammando Filippo, Massimiliano De Pasquale, Degenaar Nathalie, Melania Del Santo, D'Elia Valerio, Tiziana Di Salvo, Doyle Gerry, Falanga Maurizio, Fan XiLong, Robert D. Ferdman, Feroci Marco, Fraschetti Federico, Duncan K. Galloway, Angelo F. Gambino, Gandhi Poshak, Ge MingYu, Gendre Bruce, Gill Ramandeep, Götz Diego, Gouiffès Christian, Grandi Paola, Granot Jonathan, Güdel Manuel, Heger Alexander, Craig O. Heinke, Homan Jeroen, Ioria Rosario, Iwasawa Kazushi, Izzo Luca, Ji Long, Peter G. Jonker, José Jordi, Jelle S. Kaastra, Kalemci Emrah, Kargaltsev Oleg, Kawai Nobuyuki, Keek Laurens, Komossa Stefanie, Kreykenbohm Ingo, Kuiper Lucien, Kunneriath Devaky, Li Gang, Liang En-Wei, Linares Manuel, Longo Francesco, Lu FangJun, Alexander A. Lutovinov, Malyshev Denys, Malzac Julien, Manousakis Antonios, McHardy Ian, Mehdipour Missagh, Men YunPeng, Méndez Mariano, Roberto P. Mignani,

Scientific requirements

- Simultaneous spectral-timing-polarimetry observation of the time-variable Universe in a wide X-ray energy band

Item	Requirement	Scientific drivers
Effective area	≥ 0.4 m^2 (focused) ≥ 3 m^2 (collimated)	EOS, BH spins, GR effect
Energy range	0.5-30 keV	Broadband spectrum, multi-wavelength variability, GR effect
Energy resolution	≤ 180eV@6 keV	Broad iron line measurement
Time resolution/accuracy	≤10μs / 2μs	Sub-millisecond variability
Polarimetry	MDP ~1.6%	Magnetic field, emission mechanism, emission geometry
Eff. Area for polarimetry	≥ 380cm^2@3keV	
Wide field monitoring	FoV ≥ 3 Sr	
Throughput	> 90% @10Crab	Bright sources

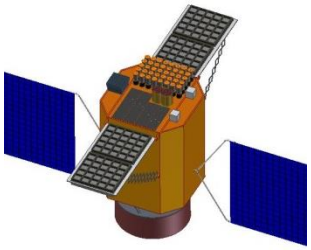
eXTP payload concept

- Short focal-length for multiple modules.
- Deployable panel for large area collimated modules.
- High modular silicon drift detectors for high spectral/timing observation, and high throughput with negligible pile-ups.
- Polarimeter with imaging capability.
- Wide field monitor.

Artistic view of the eXTP satellite (by CAST)

A brief history of the eXTP concept

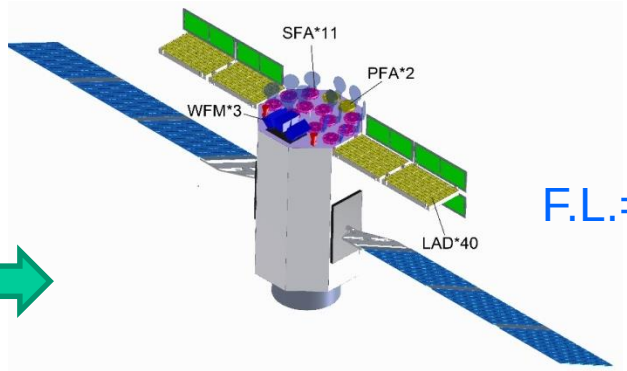
XTP: Phase 0: 2009-2011
Phase A: 2011-2015
supported by CAS



XTP 2011

XTP 2013

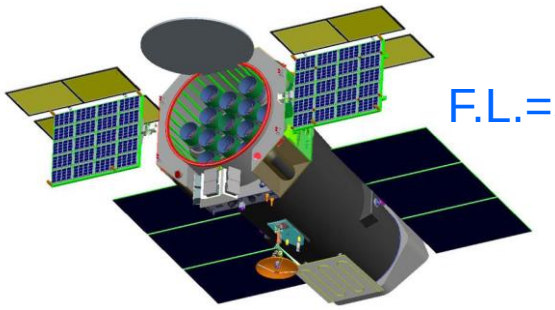
2015



F.L.=4.5m

eXTP 2016

LOFT phase A:
2011-2014
ESA M3 candidate



F.L.=5.25m

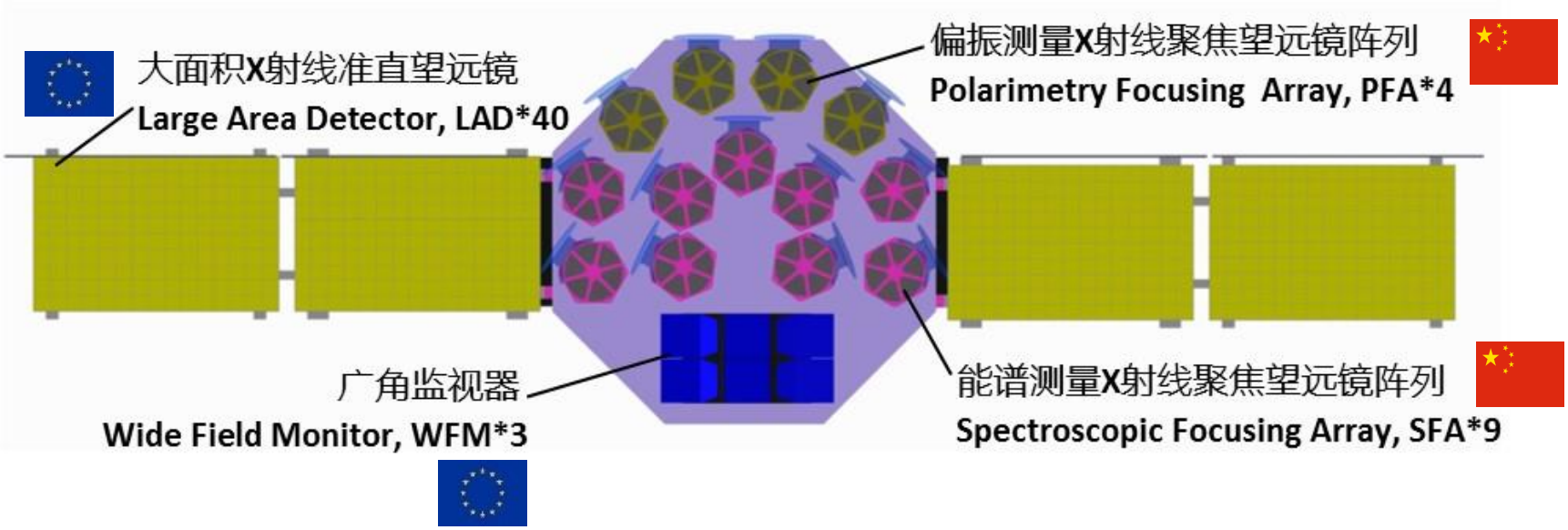
eXTP 2017

First XTP-LOFT meeting 2014
eXTP meeting ~ 2 per year since 2015

2018: The extended Phase A study in China with support from European participating countries

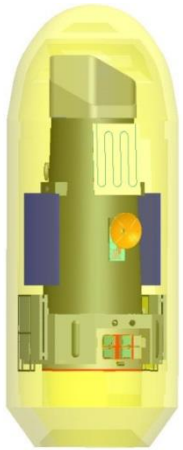
eXTP payload configuration

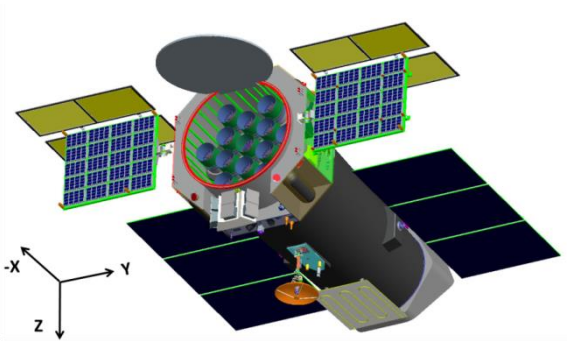
Payload	Configuration	Optics	Detector	Expected eff. area (m^2)	Time ref. (μs)
SFA - Spectroscopic Focusing Array	9 telescopes	Wolter-I	SDD	0.74 m^2@2 keV	10
LAD - Large Area Detector	40 modules	MCP collimator	SDD	3.4 m^2@8 keV	10
PFA - Polarimetry Focusing Array	4 telescopes	Wolter-I	GPD	495 cm^2@3 keV	500
WFM - Wide Field Monitor	6 cameras	1.5D coded mask	SDD	4.1 Sr (FOV)	10



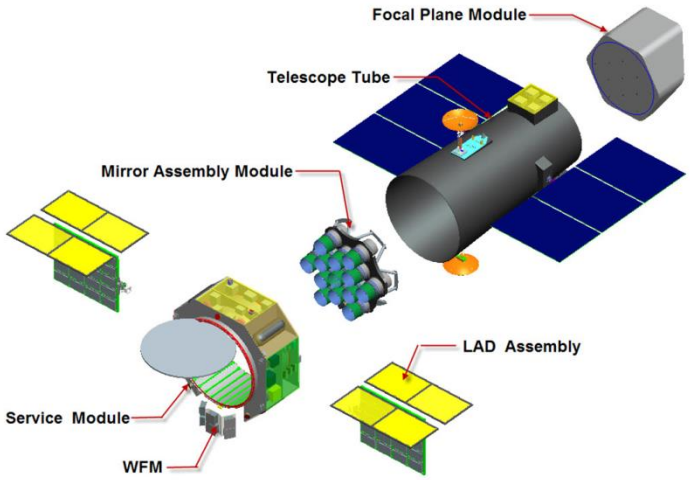
eXTP Mission overview

Parameter	Value
Orbit	550km, inclination 0°
Pointing	3-axis stabilized, < 0.01° (3σ)
Launch	LM7 + upper stage, @Wenchang
Launch mass	4500 kg
Telemetry	3.2 Tb/day (X-band or Ka-band)
Burst alert	BeiDou Navigation Satellite System; VHF transmitter (SVOM); Tracking and Data Relay Satellite System
Ground Stations	Sanya (China), Malindi (Italy)
Mission duration	5 years (goal 8 years)
Launch date	~ 2025



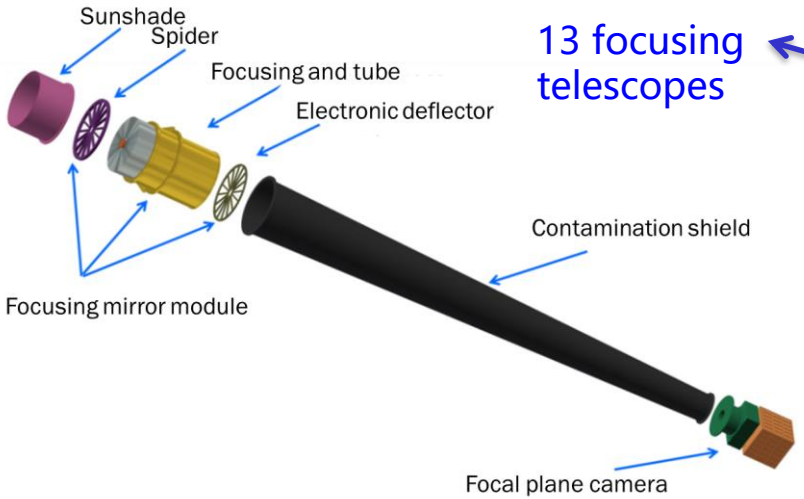


16.8 mm × 3.95 mm × 11.4m

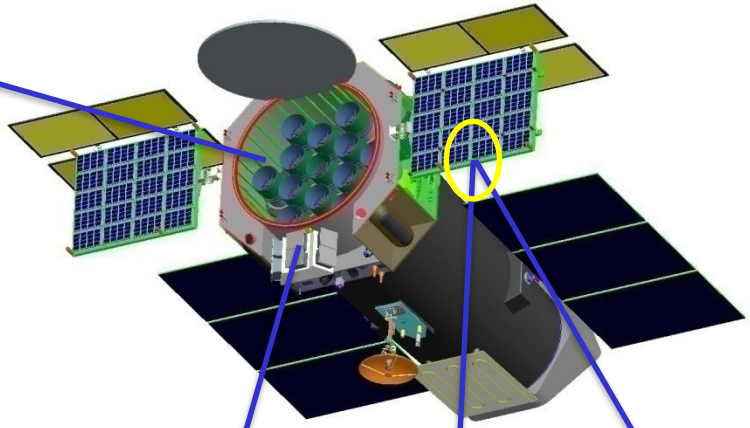


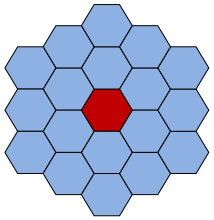
Accommodation concept by CAST

eXTP payload accommodation

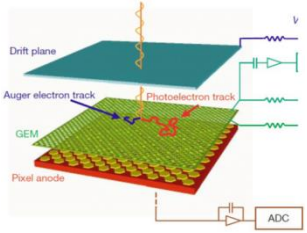


13 focusing telescopes

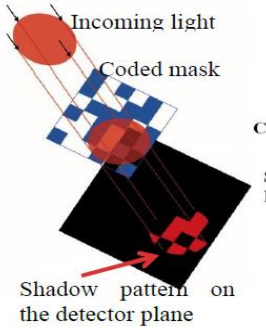


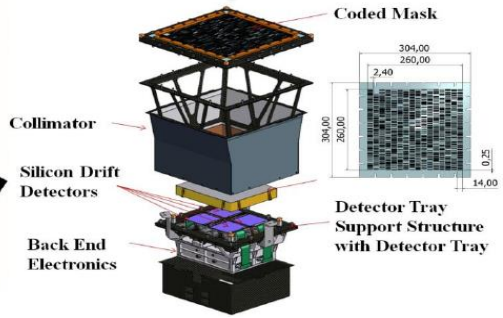


SDD camera (9)

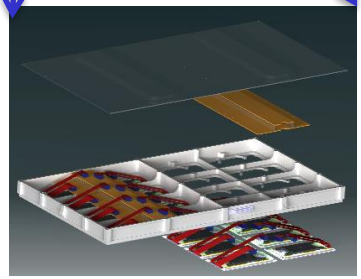


GPD (4)





WFM cameras (6)

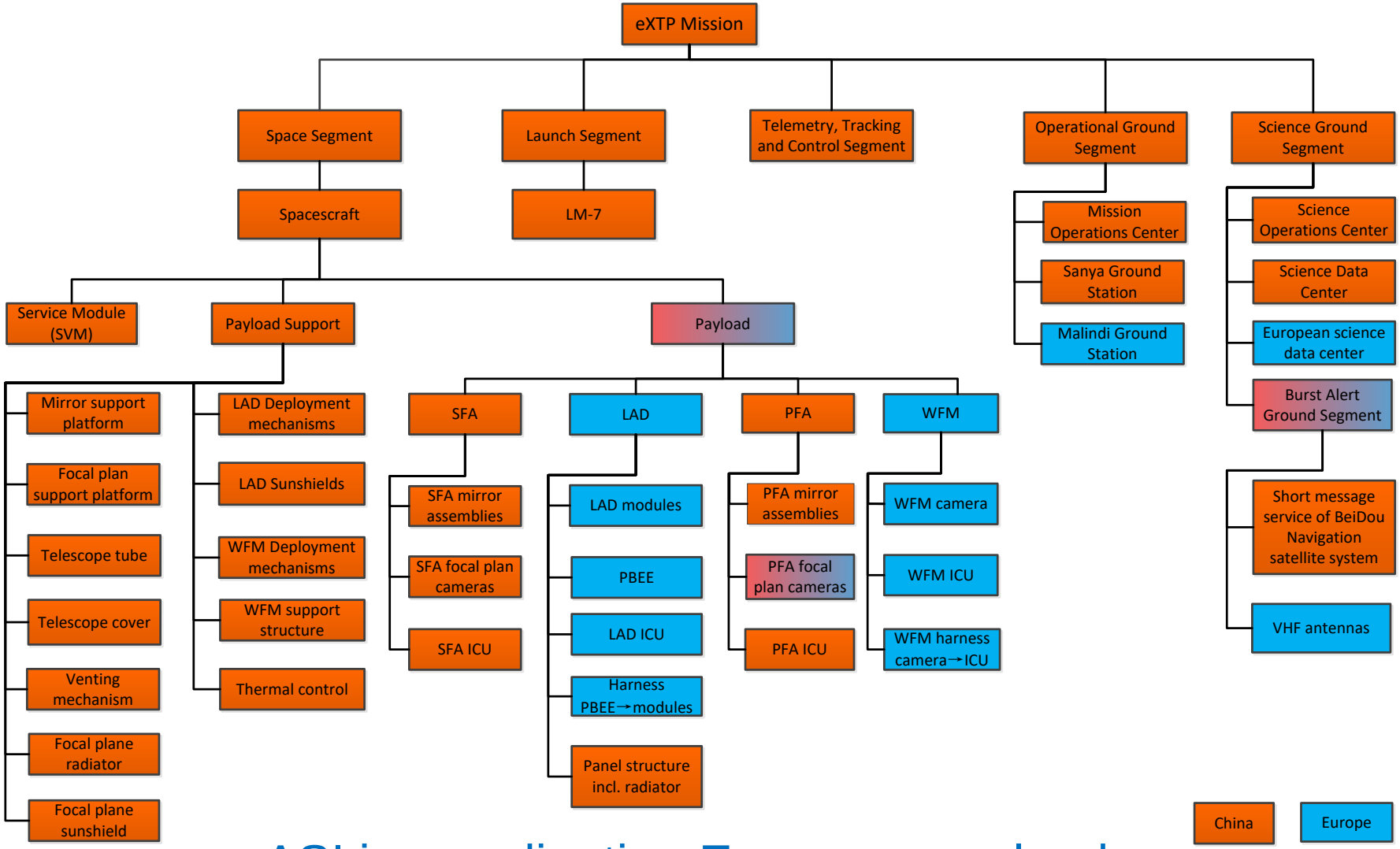


LAD modules (40)

Potential European Participants

esa is considering eXTP MoO.

eXTP System Product Tree with Main Responsibilities

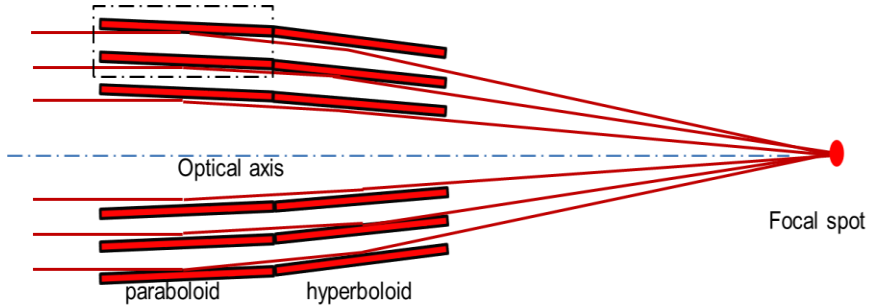


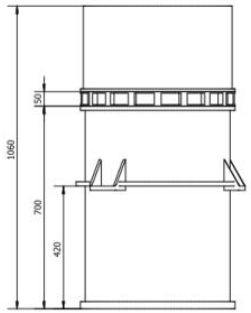
ASI is coordinating European payloads.

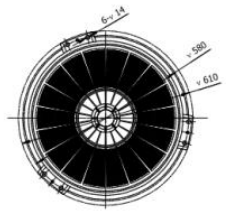
The optics

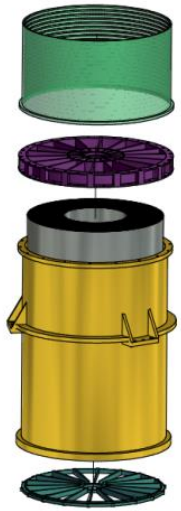
Mirror module specifications

Focal length	5.25 m
Aperture	≤ 500 mm
Colleting area	≥ 820 cm²@2 keV ≥ 550 cm²@6 keV
Energy range	0.5~10 keV
Field of view	> 12′
Angular resolution	SFA（9）: 1′(HPD)、3′（W90） PFA（4）: 30(15)″(HPD)
Temperature range	20±2℃
First resonance frequency (prelimnary)	≥ 80Hz (axial direction) ≥ 40Hz (lateral direction)
Weight	≤ 100 kg





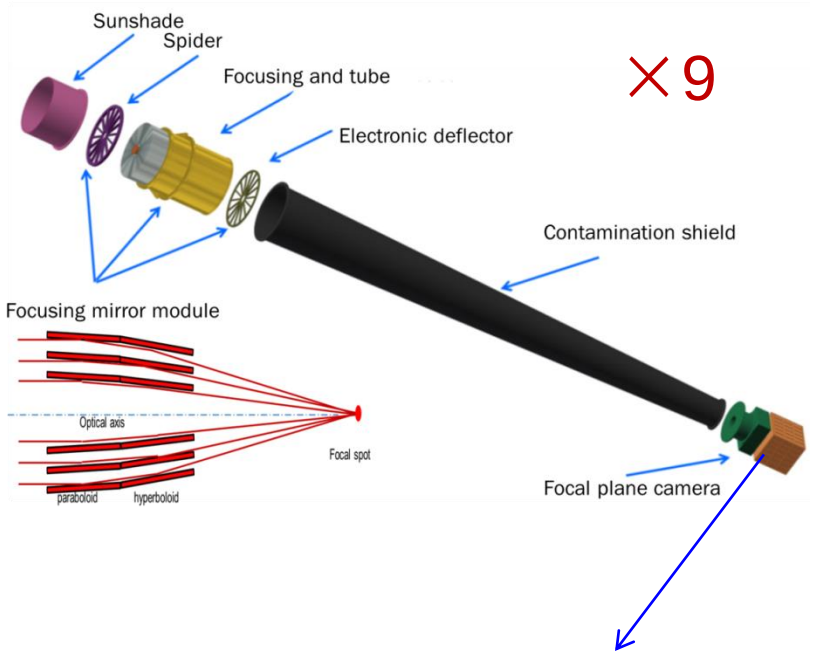


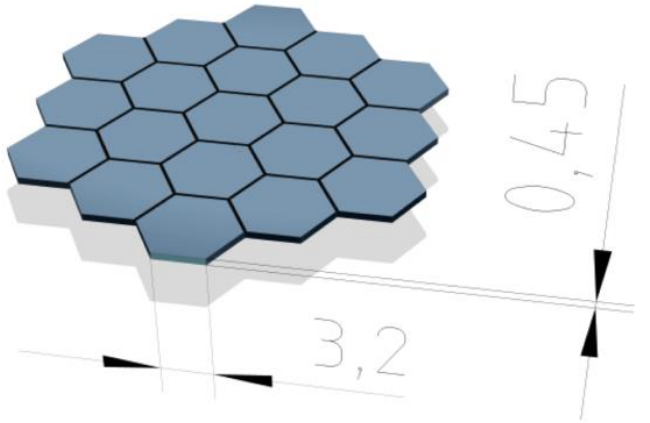


- 13 flight moudles
- Grazing incidence Wolter-I
- 40 shells per module
- P+H = 60cm
- Ni electroforming replication

SFA – Spectroscopy Focusing Array

- Large collecting area achieved by multiple optics with short focal length.
- 9 grazing incidence Wolter-I optics with 5.25 m F.L., 40 shells/module
- Non-imaging, 1′ (HPD), 3′ (W90), 12′ FoV
- 19-cell SDD array: multi-pixel to enable background subtraction
- Energy range: 0.5-10 keV
- Energy resolution: ≤ 180 eV @ 6 keV
- Time resolution: 10 μs
- Absolute timing accuracy: 2 μs
- Dead time: < 5% @ 1 Crab
- Sensitivity: 4.1×10^{-15} erg/cm^2/s (3σ, 10ks)





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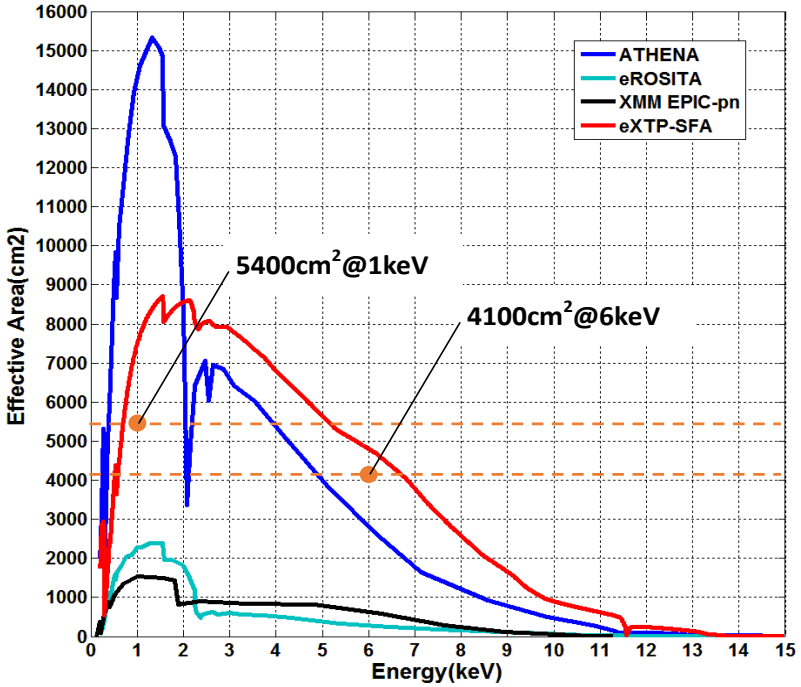
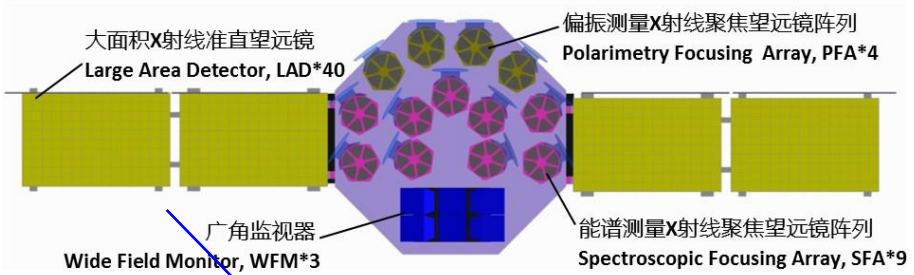
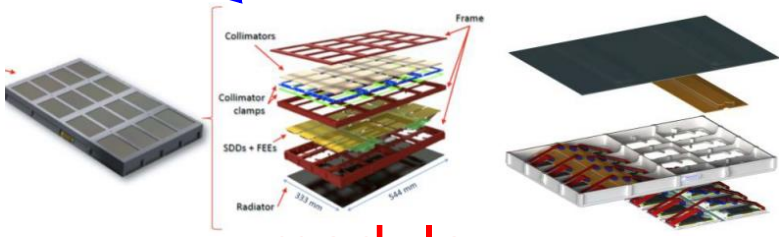


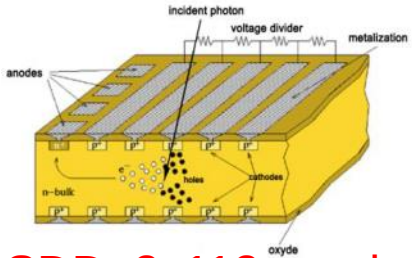
LAD – Large Area Detector

- Spectral and timing observation
- 40 modules on 2 deployable panels
- Collimated, large area SDD detector
- Energy range: 2-30 keV (goal 50 keV)
- Energy resolution: < 240eV @ 6 keV
- Field of View: 1° (FWHM)
- Time resolution: 10 μs
- Absolute time accuracy: 2 μs
- Dead time: < 0.5% @ 1 Crab
- Background: < 3 mCrab
- Total effective area: 3.4 m² @ 8 keV

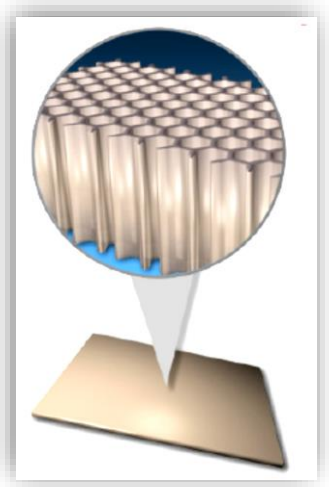




module



SDD: 2x112 anodes, pitch = 970 μm



MCP collimator

Thermal/optical filter

LAD – Large Area Detector

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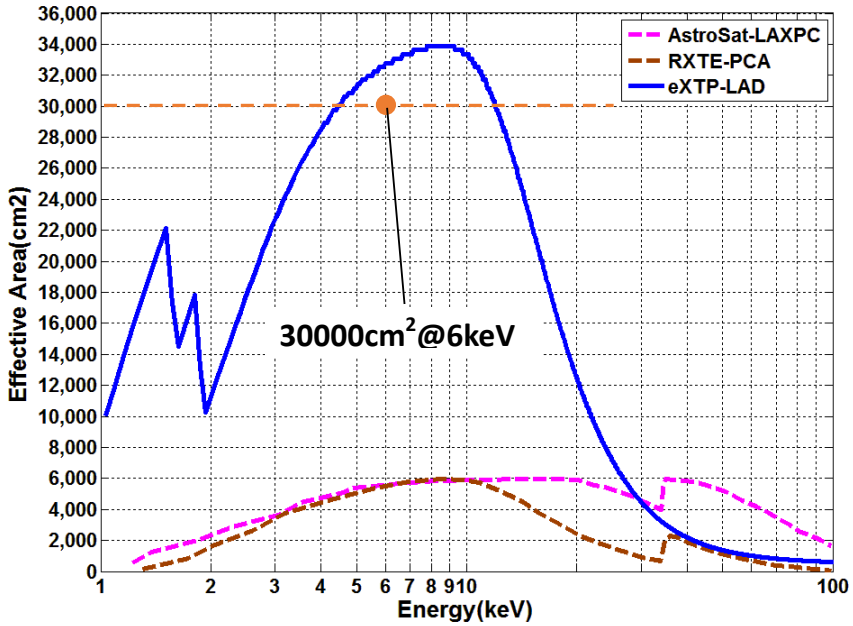
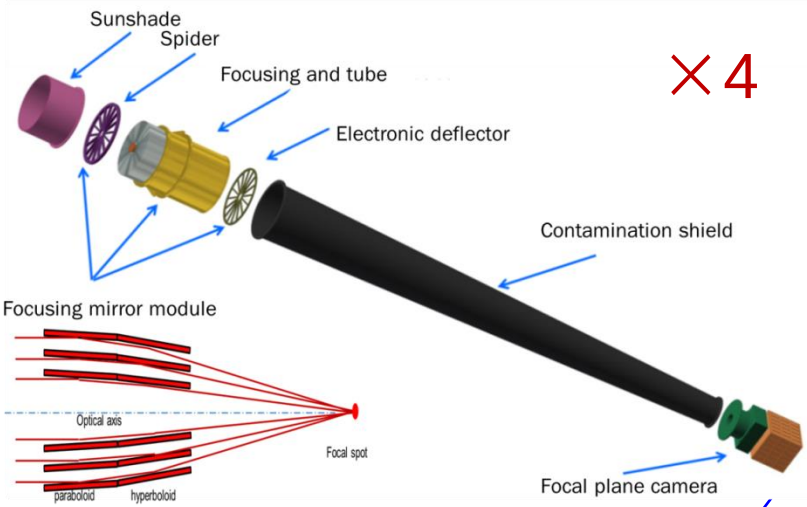
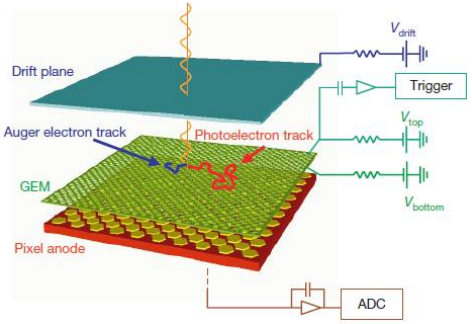
- Dead time: < 0.5% @ 1 Crab
- Background: < 3 mCrab
- Total effective area: 3.4 m² @ 8 keV



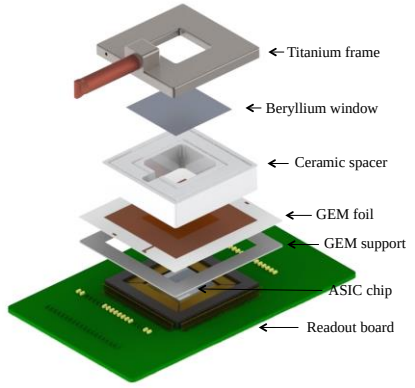
PFA – Polarimetry Focusing Array

- Large collecting area achieved by multiple optics with short focal length.
- 4 grazing incidence Wolter-I optics with 5.25 m F.L., 40 shells/module
- Imaging, resolution ≤ 30″ (HPD, goal 15″)
- Field of view: 8′
- Gas Pixel Detector (GPD): photo-electron tracking
- Energy range: 2-8 keV
- Energy resolution: ≤ 1.8 keV @ 6keV
- Time resolution: 500 μs
- Absolute timing accuracy: 2 μs
- MDP: < 1.6% (10^6 s, 1 mCrab) (1% for unpolarized X-ray reached in lab)





Designed by the INFN-Pisa group (Bellazzini et al.)



GPD prototype (Tsinghua)

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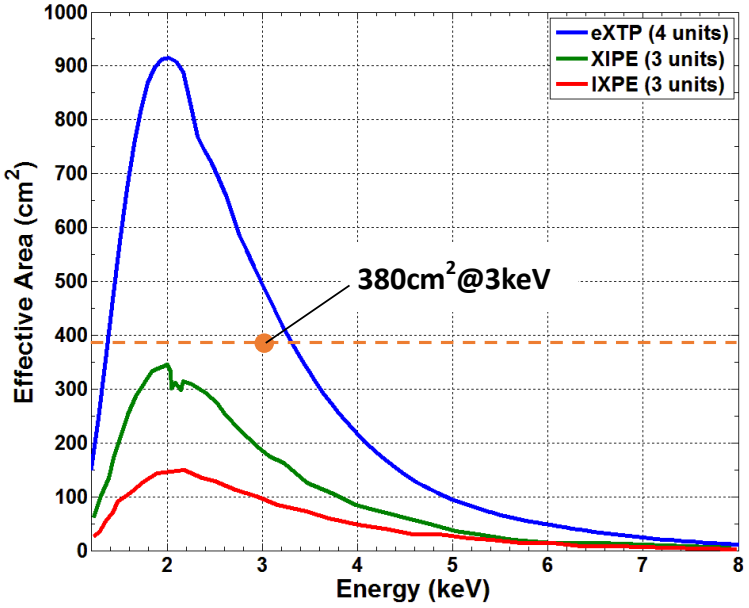
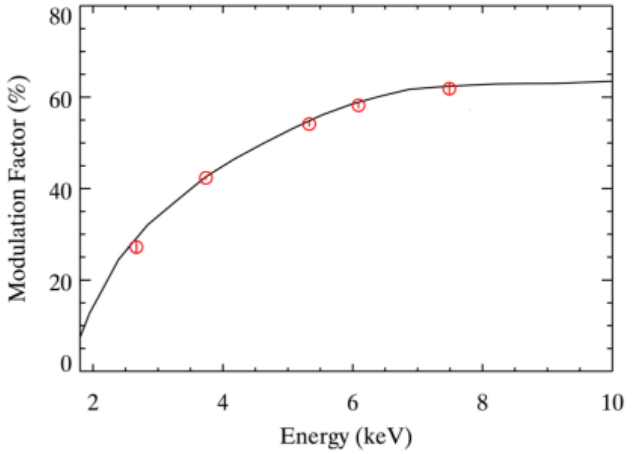
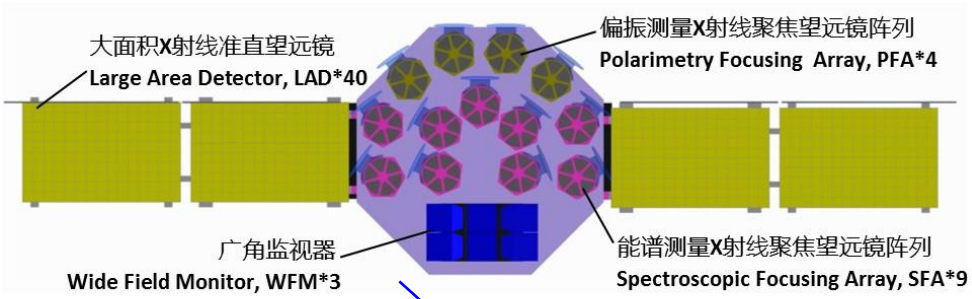
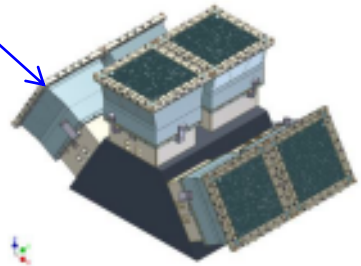


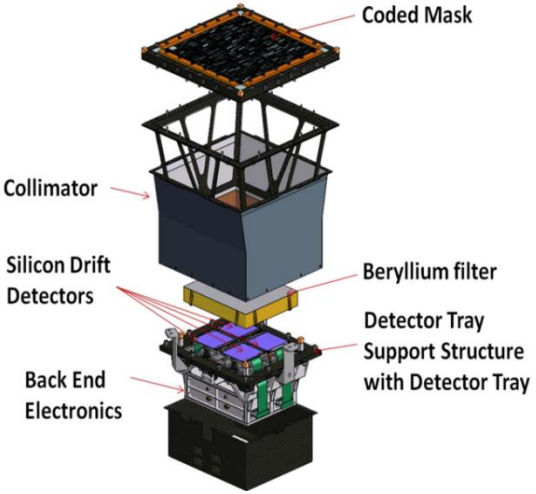


WFM – Wide Field Monitor

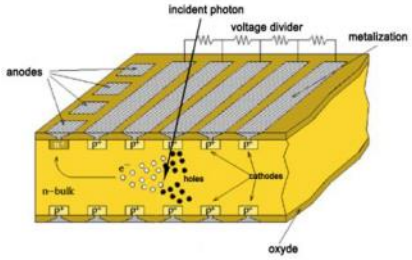
- 3 units (6 cameras)
- 2D Imaging, 5′ (FWHM) resolution
- Location accuracy: ≤ 1′
- Field of view: ≥ 3.2 Sr (at 20% response)
- Energy range: 2-50 keV
- Energy res.: ≤ 300eV @ 6keV
- Time resolution: 10μs
- Absolute time accuracy: 2μs
- Peak sensitivity (5σ): 1Crab (1s), 5mCrab (50ks)



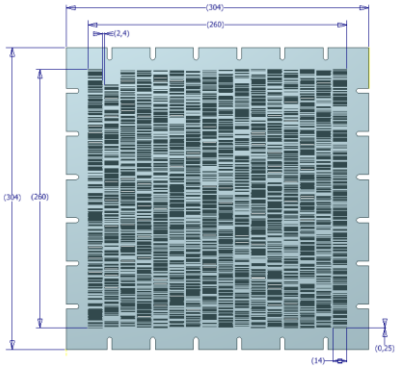




Camera module



SDD: 2x384 anodes, pitch = 169μm



1.5D coded mask

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- 2D Imaging, 5′ (FWHM) resolution
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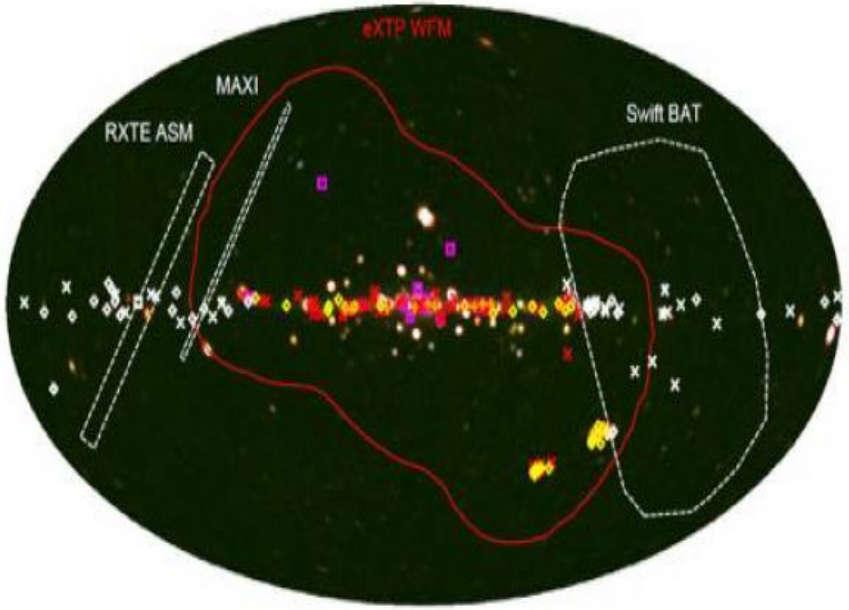


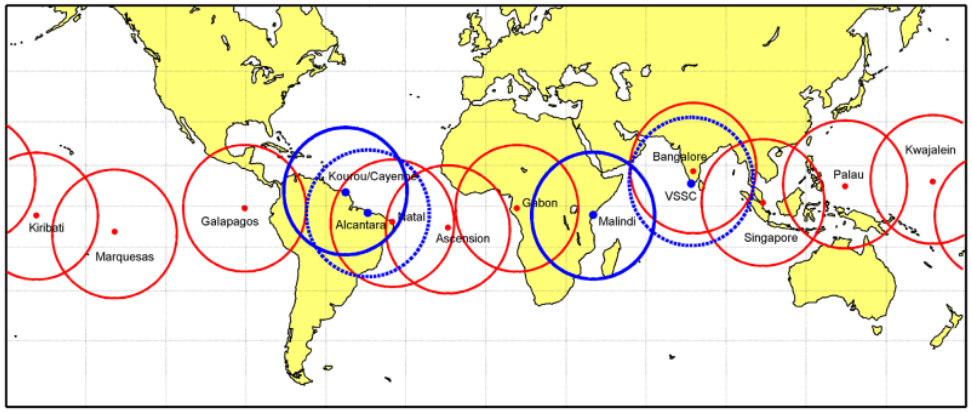
WFM field of View. (Background map courtesy of T. Mihara, RIKEN, JAXA, and the MAXI team)

Observation mode

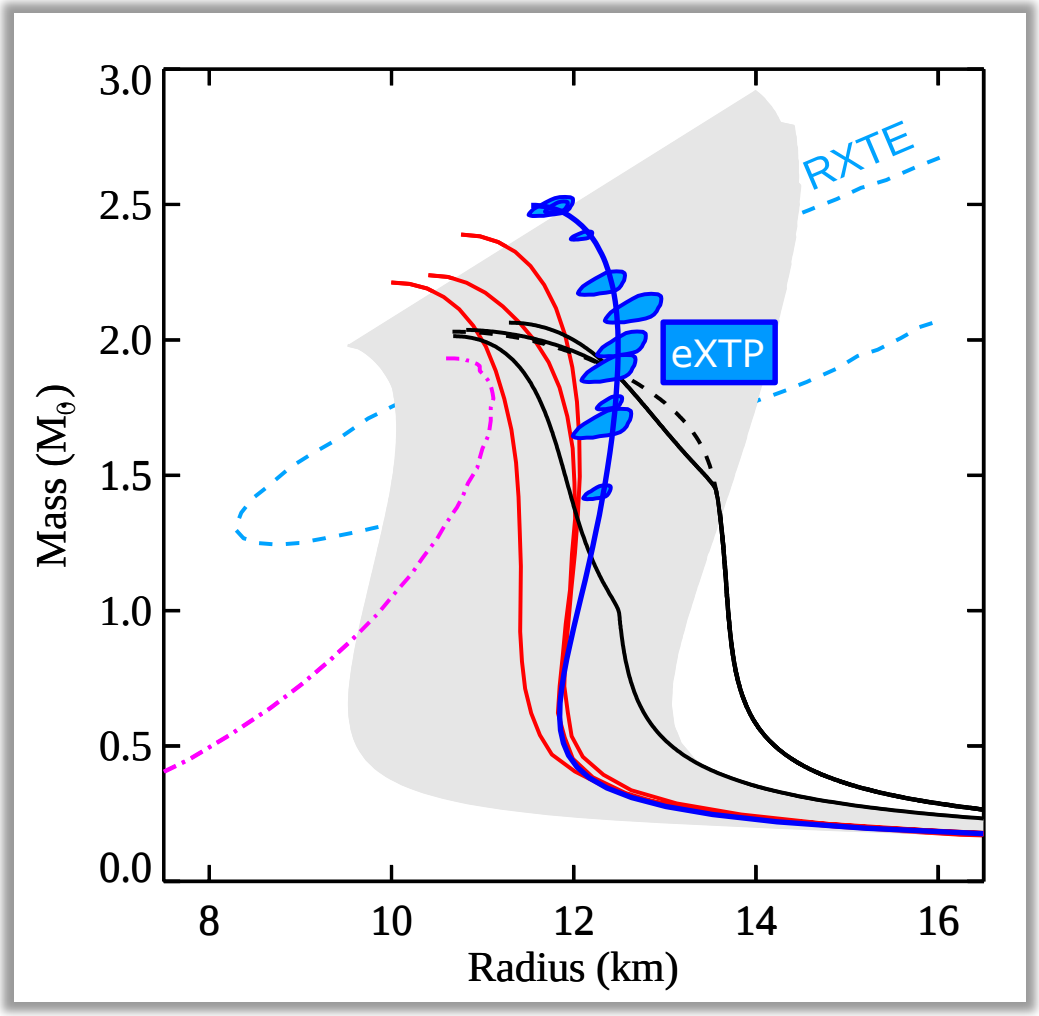
- Pointed
  - ape < 0.01° (3σ)
  - Up to 10^6 s per observation
- Follow-up
  - Triggered by the WFM onboard
  - Triggered by other missions through scientific centers
  - The S/C has the ability to slew 30° and stabilize in 10 minutes
    - implications for GRB afterglow polarimetry?
- Small area sky scan
  - PSF calibration and ape verification of SFA and LAD

Transient event alert download and ToO upload

- Download link requirement: 65%<30s; 95%<120s
- Baseline solution: BD-3 short message system for upload (TBC) and download link
  - The basic BDS-3 constellation has been successfully deployed after the 18th and 19th of the BDS-3 satellite launched on Nov 19th, 2018, and will be put into operation before the end of this year.
  - BDS with global coverage will be completed by the end of 2020 with total 35 satellites on orbit.
- Backup:
  - burst alert: the VHF system designed for SVOM
  - ToO upload: TT&C or the relay satellites



Spectral-Timing Mapping EOS with eXTP



Neutron or Quark Star?

Detailed simulations carried out to evaluate fitting procedure and accuracies (Lo et al. 2013, ApJ).

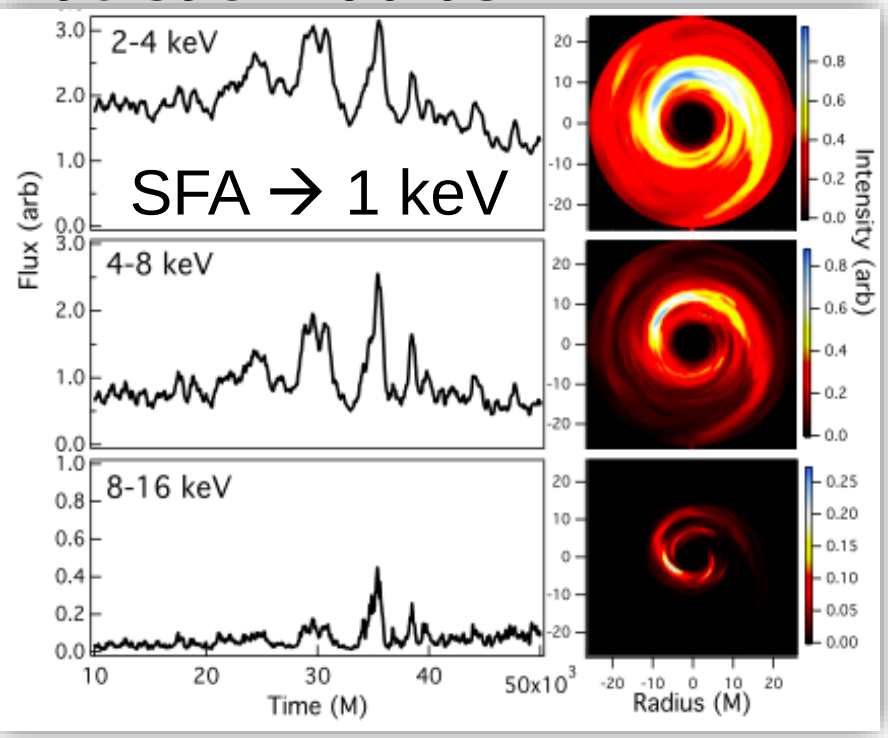
Few % accuracy needs ~10^6 photons: 3-4m^2 area crucial.

Multiple same-source cross-checks.

USING ONLY KNOWN SOURCES, EXTP'S PULSE PROFILE MODELLING MEASUREMENTS WILL MAP THE M-R RELATION AND HENCE THE EOS.

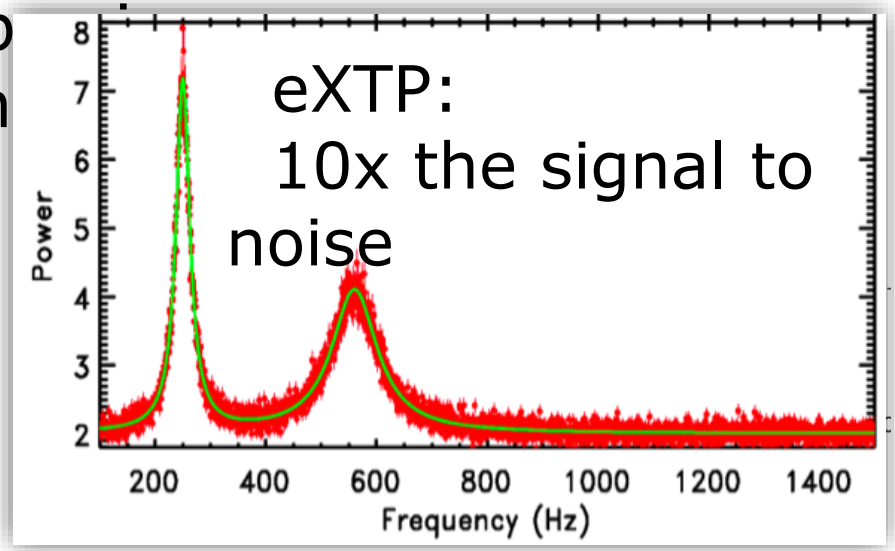
Spectral-Timing for strong field gravity

General Relativity predicts p
orbital and epicyclic frequen
at each radius



Wellons et al. 2013

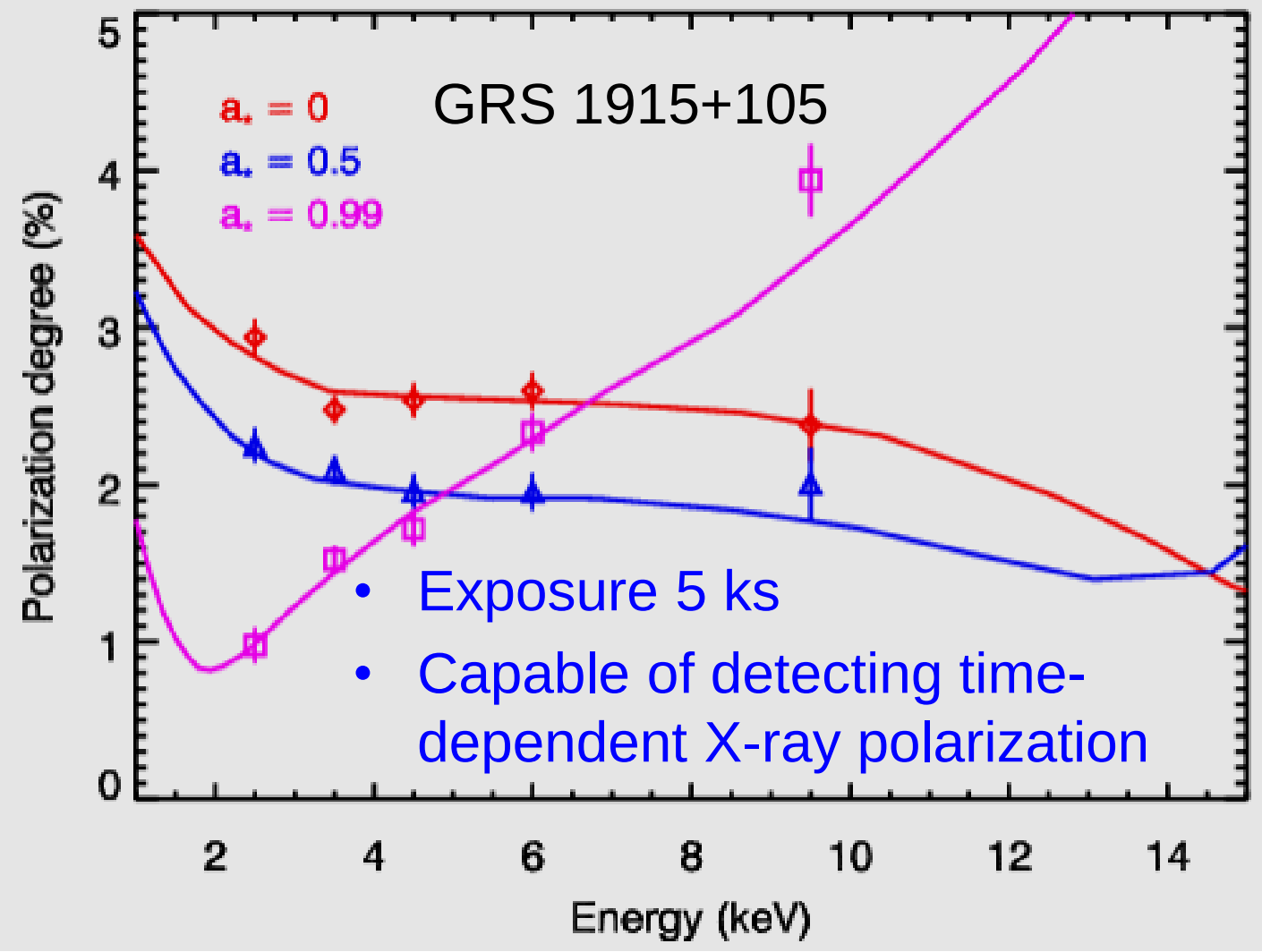
Orbiting inhomogeneities make frequencies observable



- Strong gravity dynamical frequencies <u>just</u> detected in current (RXTE) data
- eXTP diagnoses strong field gravity very precisely by:
  - timing of the <u>flux variations</u>
  - time resolved <u>spectroscopy</u>

  at very high signal to noise
- Uses known phenomena

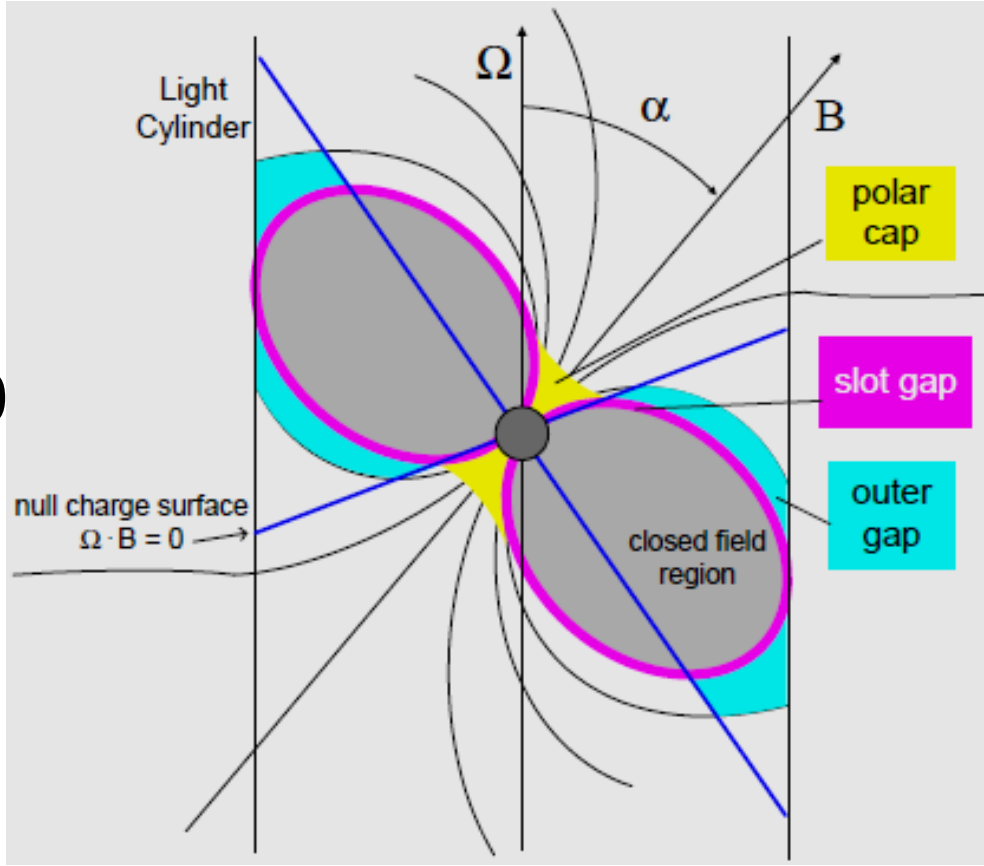
Spectral-Polarimetry for BH spin



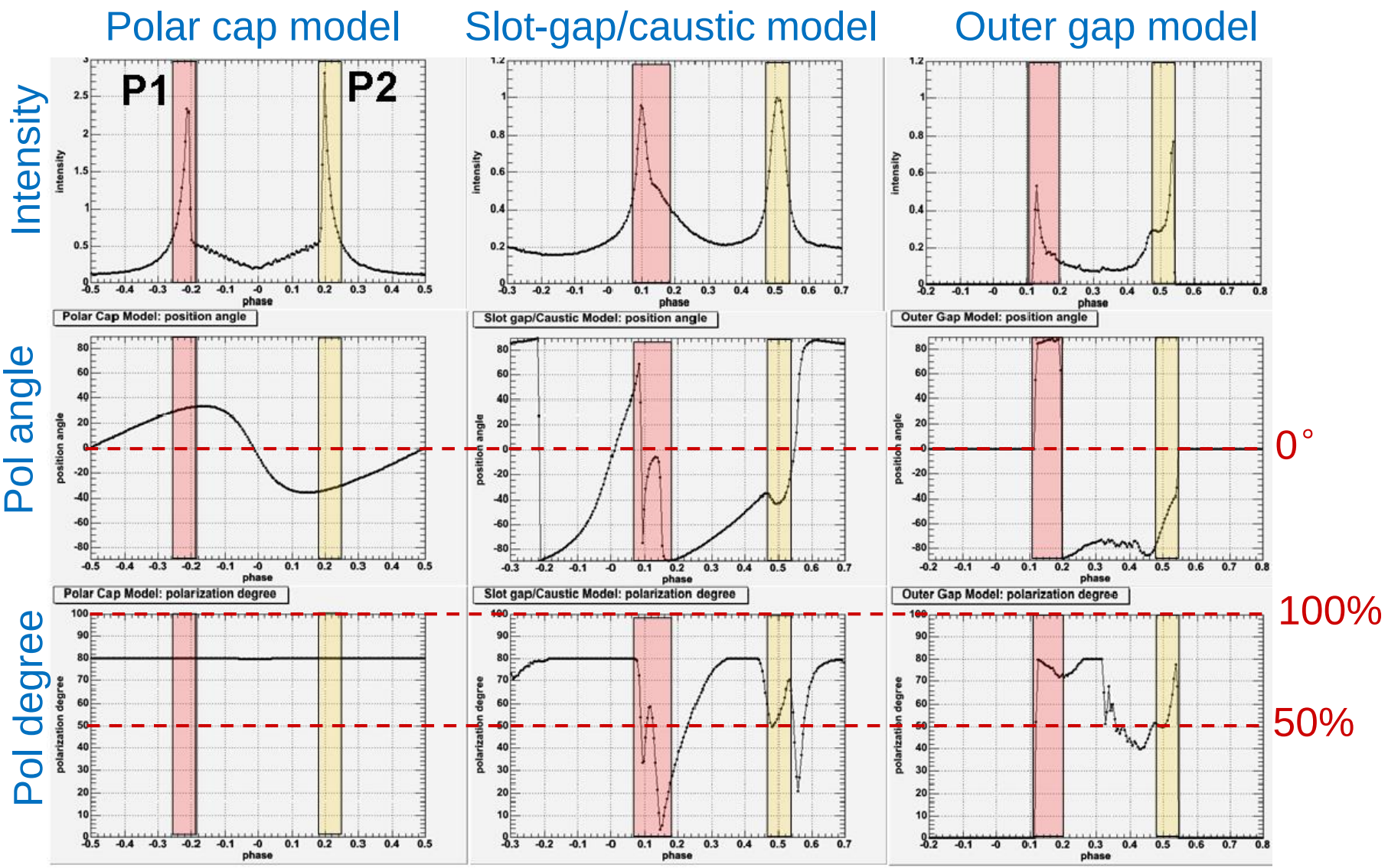
To be complemented by simultaneous SFA+LAD with Continuum Fitting & Fe-line BH spin measurement

Rotation-powered pulsars

- Three competing models
  - Polar cap (Daugherty & Harding 1996)
  - Slot gap (Muslimov & Harding 20
  - Outer gap (Romani 1996; Takana 2007)

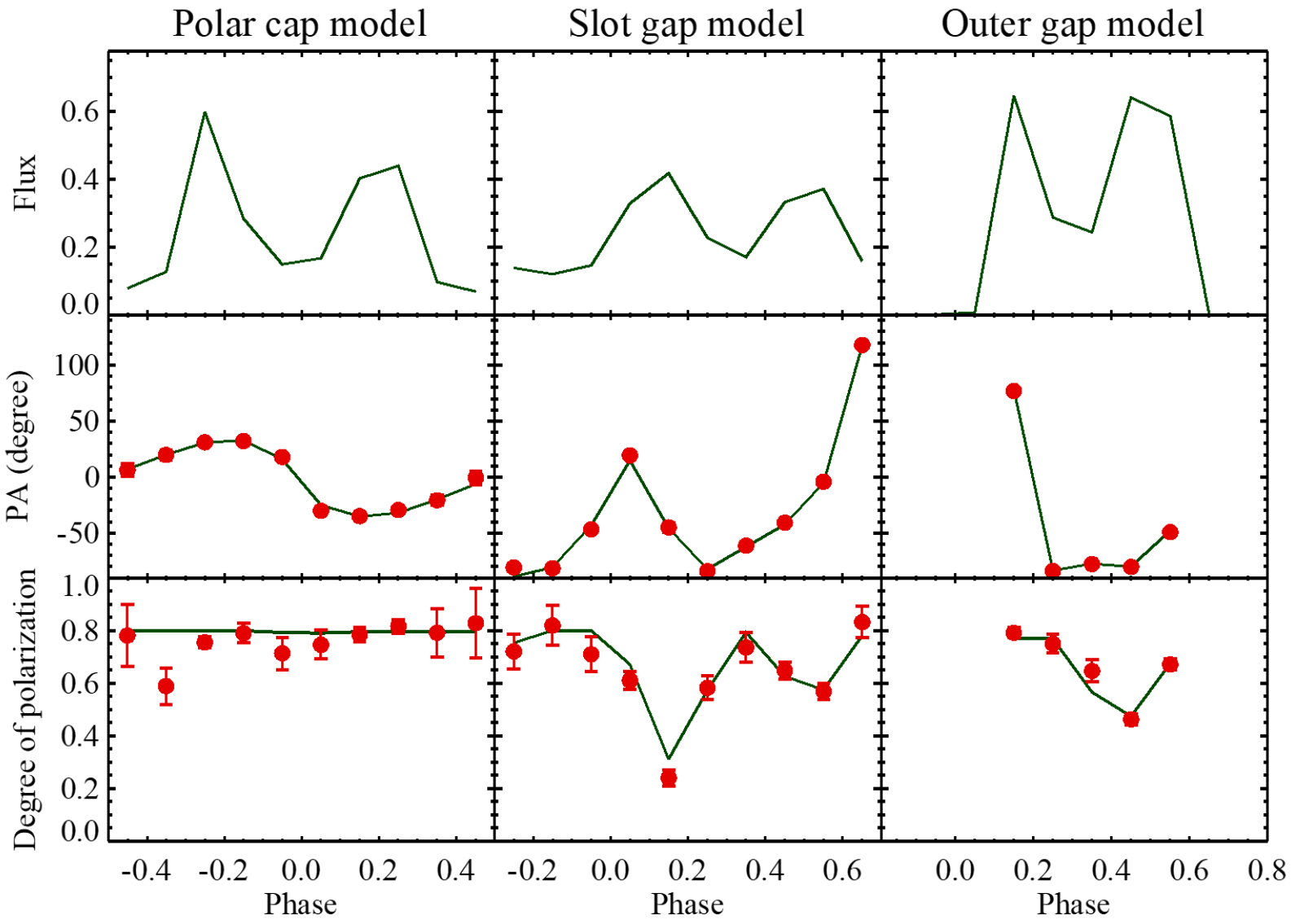


Timing-Polarimetry to Pulsars



SFA & LAD → precise phasing

eXTP discriminates pulsar models

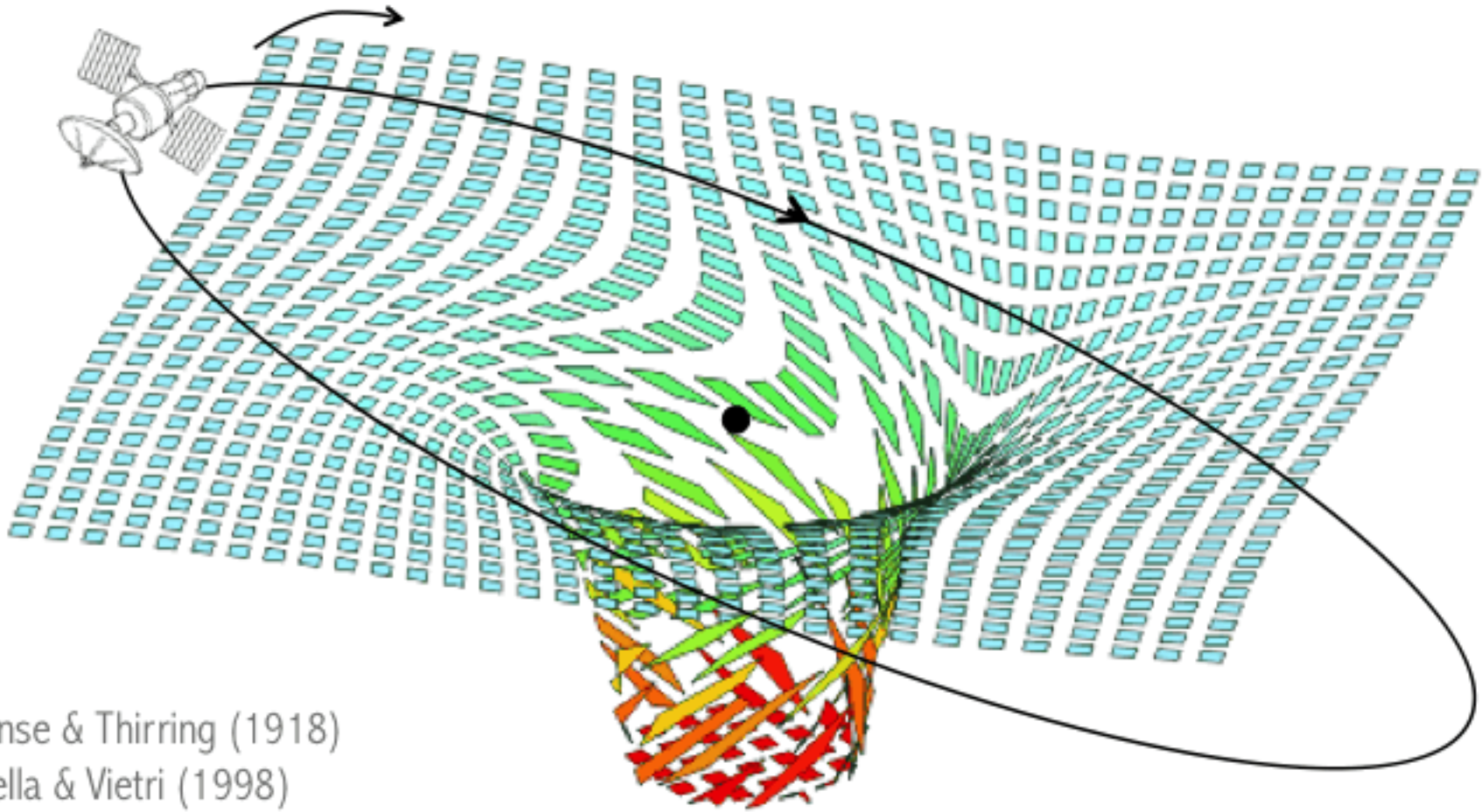


SFA & LAD → precise phasing

Timing-Polarimetry for Frame Dragging

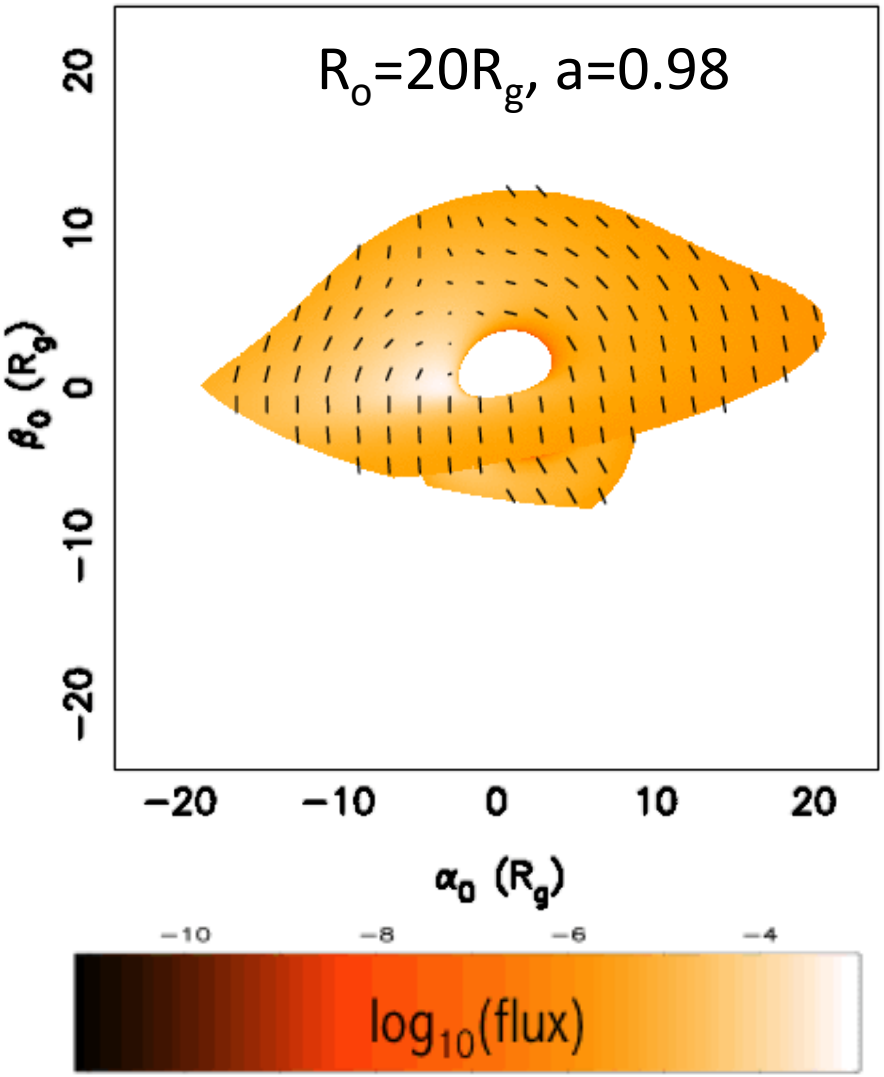
A spinning black hole **distorts** space and time

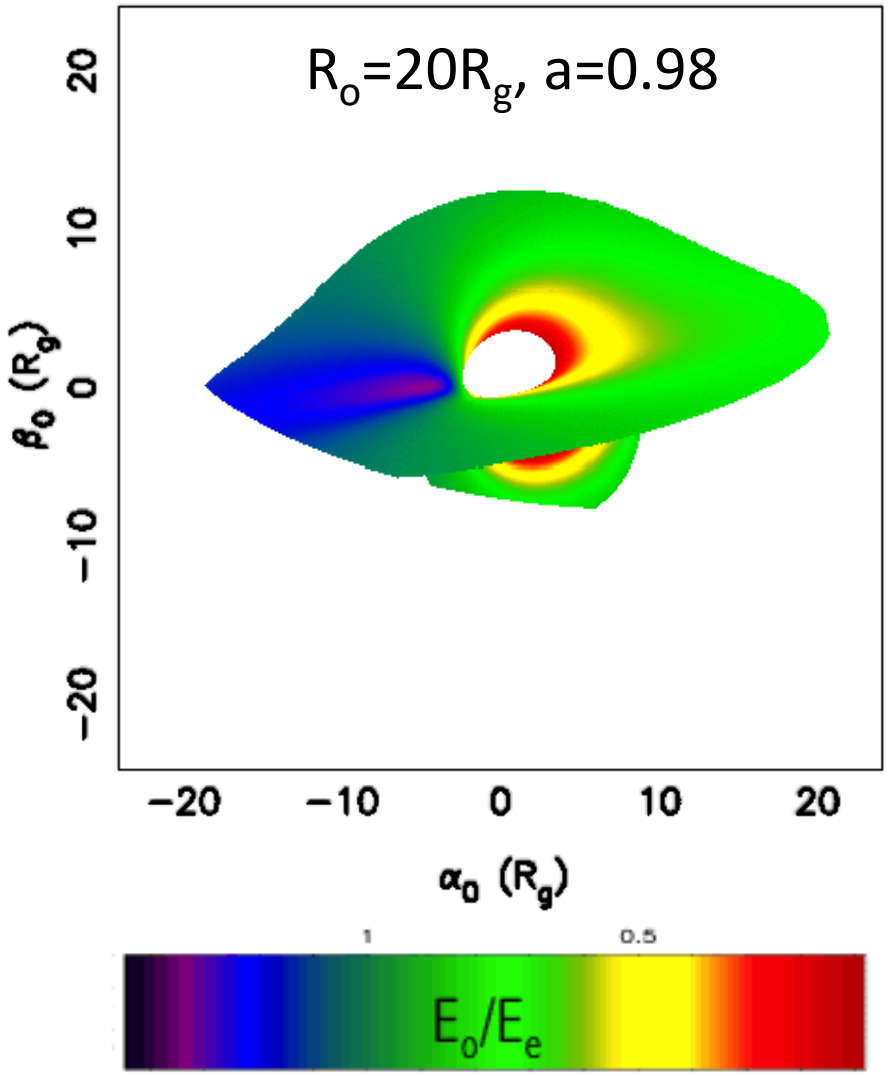
The satellite's motion is **influenced** by the spin of the black hole



Lense & Thirring (1918)
Stella & Vietri (1998)

Movies: high inclination (i=70^o)

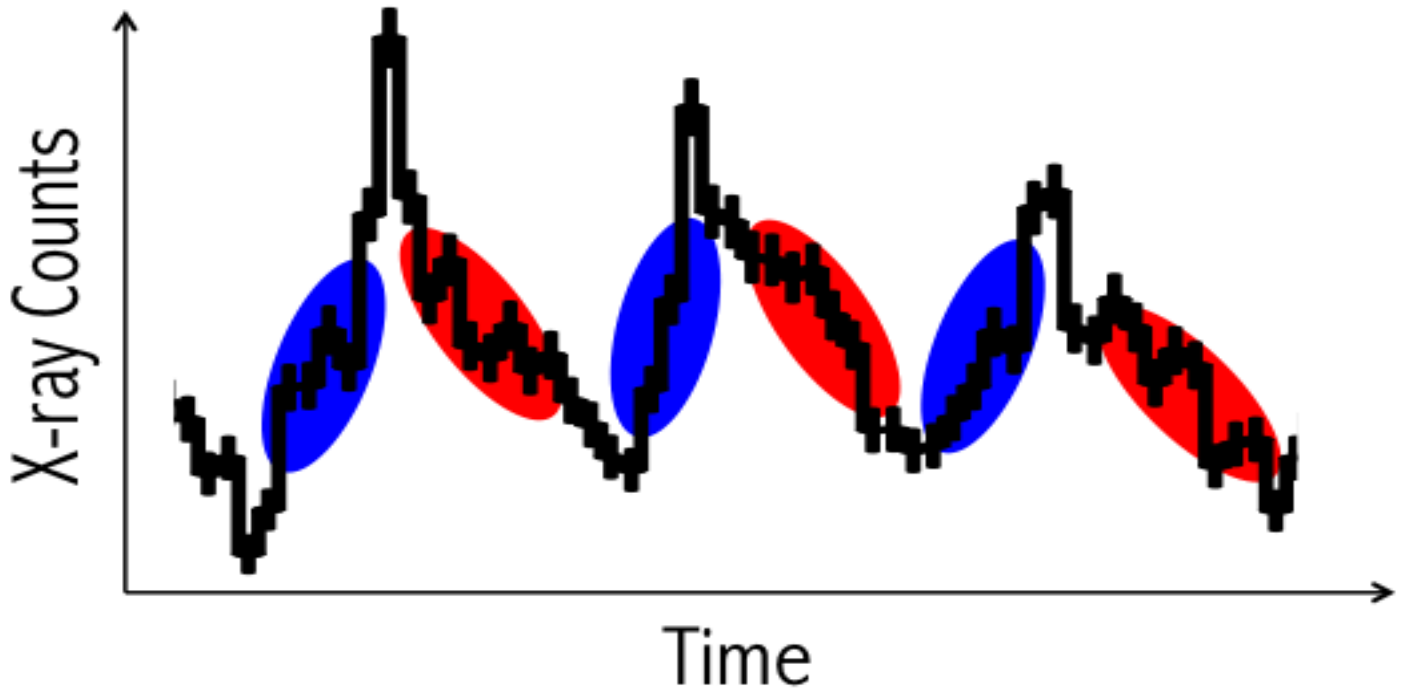




www.youtube.com/watch?v=ieZYYfCapJg&feature=youtu.be

Ingram et al (2015)

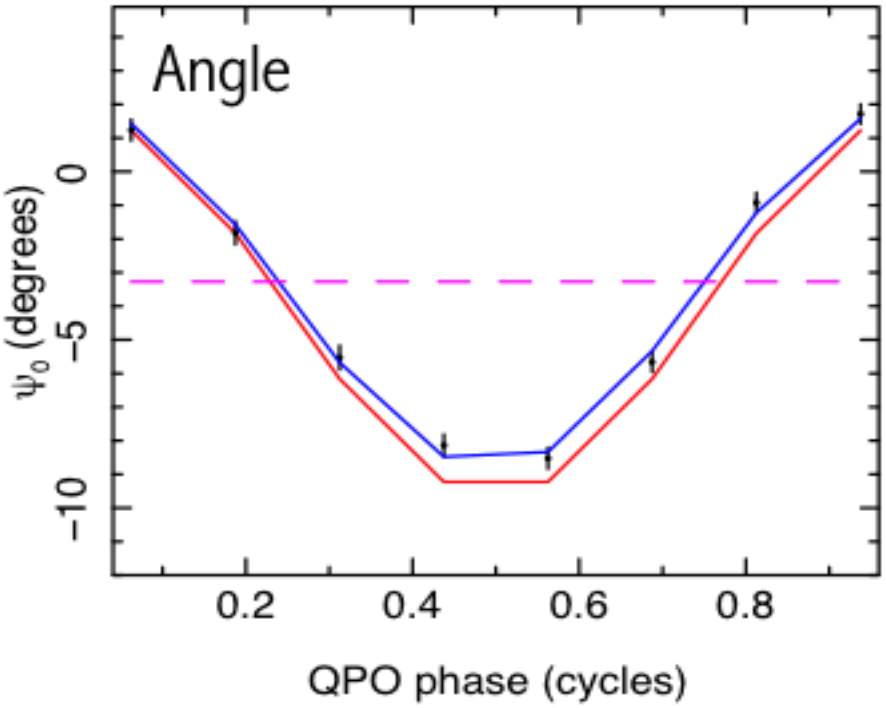
Phase folding

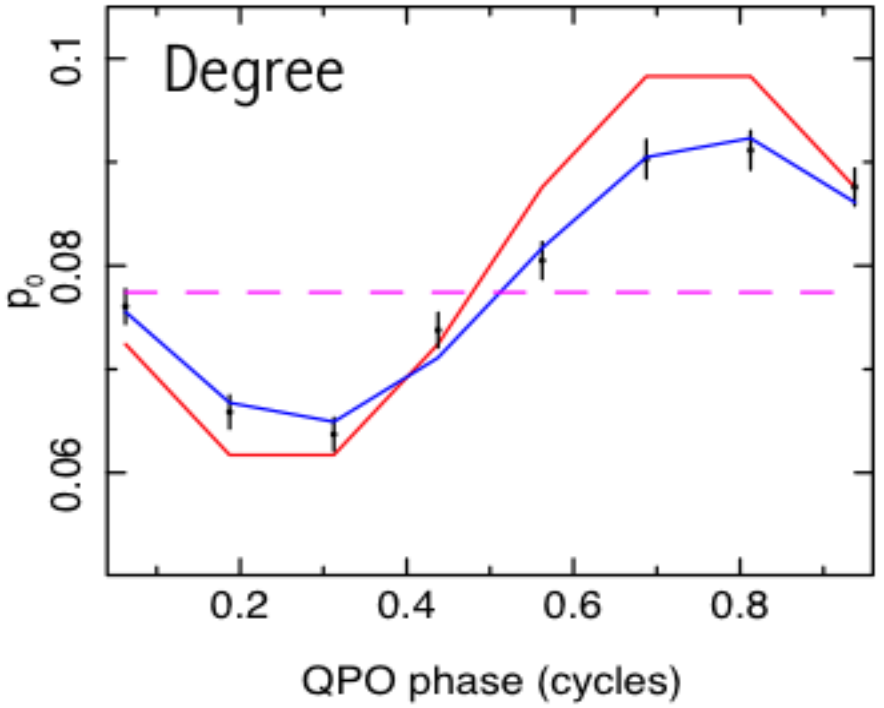


p_0 & ψ_0 p_0 & ψ_0

SFA & LAD → precise phasing

Phase folding: LAD+SFA+PFA



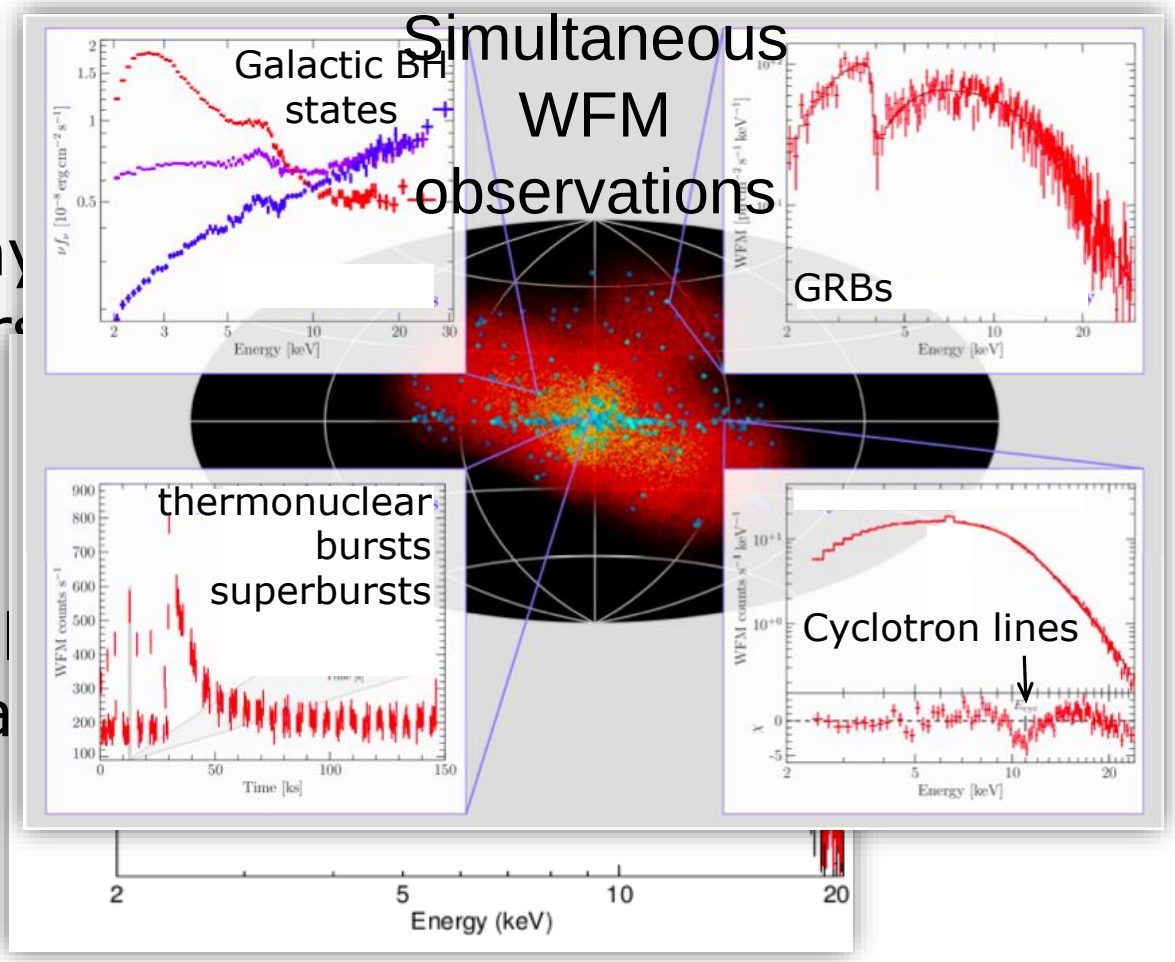


- 32.768ks exposure
- $\langle p_0 \rangle = 8\%$, $\sigma_{p0} = 1.4\%$, $\langle \psi_0 \rangle = -4$ degrees, $\sigma_{\psi_0} = 4$ degrees
- Flux = 1 photon $cm^{-2}s^{-1}$ assuming absorbed power-law with $\Gamma = 2$ and $N_h = 1 \times 10^{22} cm^{-2}$
- 40 LAD modules, 2 GPD units

Observatory science

- EXTREME-THROUGHPUT WITH SFA & LAD
- VERY WIDE ANGLE MONITORING WITH WFM

- Accretion physics
- Magnetospheric phy
- Thermonuclear bur
- Magnetars
- Gamma ray bursts
- Tidal disruptions
- Cataclysmic variabl
- Terrestrial γ-ray fla
- Flare stars
- …



Progress and Plan of Phase A+

- 2018.03 CAS kicked-off the Phase A+ study in China and officially invited European member state agencies to join the study.
- 2018.05 The first eXTP International Consortium Meeting in Xiamen.
- 2018.06 Budget for eXTP development through 2020 approved by CAS.
- 2018.09 ESA and NSSC has agreed to carry out a joint study regarding a possible European contribution to the eXTP mission.
- 2018.09 All the 5 white papers had been accepted and will be published in a special issue of *Science China* in February 2019.
- 2018.10 The core team reviewed the technical and programmatic progresses with NSSC delegations in Beijing to prepare the final approval of the mission in China.
- 2018.11 Letters of Intent by European participating agencies (coordinated by ASI).
- 2018.12 Completion of the extended Phase A.
- 2018.12/2019.01 Final approval of the mission in China.

Preliminary schedule of eXTP

- Phase A+ (10 months): March-Dec. 2018
  - Key technology/components development
  - Letters of Intent by European participating agencies (coordinated by ASI)
  - Mission approval general review in China
- Phase B (12 months): Jan.-Dec. 2019
  - Preliminary definition
  - ESA MoO proposal (early 2019)
  - Letters of Commitment and MoU signature
  - SRR, PRR, Mission adoption
- Phase C (30 months): Jan. 2020 – June 2022
- Phase D (30 months): July 2022 – Dec. 2024
- Phase E1 (6 months): Jan. – June 2025
  - Launch
- Phase E2 (60 months): June 2025 – June 2030
- Phase E3 (60 months): June 2030 – June 2035

Fully funded by CAS

Budgeted through 2020.12 in China

Summary

- eXTP will offer for the first time the most complete diagnostics of compact sources with excellent spectral, timing and polarimetry sensitivity in a single mission.
- China has initiated and is leading the project, with about 20 countries and 100 international institutions involved.
- Instrument configuration and system level studies have showed that eXTP is feasible for a launch ~2025.
- The extended Phase A study fully funded and kicked-off by CAS and budget of CAS for eXTP through 2020 approved.
- Mission approval in China planned for end of 2018 and adoption at the end of 2019 with MoO participation from ESA.

Thank you for your attention!